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UNSTEADY TRANSONIC FLOWS IN A TWO-DIMENSIONAL DIFFUSER.(U)
MAY 79 M SAJBEN, J C KROUTIL F49620-77-C-0082

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UNSTEADY TRANSONIC FLOWS IN A TWO-DIMENSIONAL DIFFUSER.

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AIR BREATHING PROPULSION SYSTEMS
INLET FLOW DISTORTION

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The second and third years of the contract comprise its second phase, aimed at exploring the effects of periodic, downstream excitation on the transonic flow in a two-dimensional diffuser model. The present report covers the second year of the contract. The pulse generator was incorporated in the diffuser model, and its controls were synchronized with the optical instrumentation. The boundary-layer control system was turned for best two-dimensionality of the flow. The flowfield instrumentation was selected, and an appropriate actuator was constructed. Perturbation of the flow by the actuator was determined to be

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) acceptably small. Boundary-layer profiles were determined on all four walls, and the Mach number distribution was mapped in detail over the diffuser exit cross-section. Surface pressure distributions were measured, and spark schlieren photos were taken for the available pressure ratio range.

PREFACE

The work reported herein was conducted by the McDonnell Douglas Research Laboratories (MDRL), St. Louis, Missouri, for the United States Air Force Office of Scientific Research, Bolling Air Force Base, D.C., under contract F49620-77-C-0082. The work reported was conducted from 1 April 1978 to 31 March 1979 in the Flight Sciences Department, managed by Dr. R. J. Hakkinen. The principal investigator was Dr. M. Sajben, and the co-investigator was Mr. J. C. Kroutil. The program technical manager was Dr. D. Samaras, Air Force Office of Scientific Research.

This technical report has been reviewed and is approved.

R. J. Hakkinen
Chief Scientist, Flight Sciences
McDonnell Douglas Research Laboratories

D. P. Ames
Staff Vice President
McDonnell Douglas Research Laboratories

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1. INTRODUCTION

The present study is part of a continuing investigation of unsteady, transonic diffuser flows, with application to dynamic distortion in the inlets of fighter aircraft and airbreathing missile propulsion systems.

The investigation is focused on a simple, two-dimensional diffuser configuration displaying a weak shock shortly downstream of the throat. Flows in this configuration were found to display self-excited oscillations involving the shock and the entire subsonic flow behind it. The shock displacement amplitudes are comparable to the throat height and occur at frequencies characterized by the flow speed and the length of the divergent diffuser section. The time-mean and fluctuating properties of this flow and the dependence of these properties on shock strength have been documented[1-4].

The first year of the contract was devoted to exploring the effects of approach boundary-layer thickness. This work is complete and has been partially documented.[5]

The second and third years constitute the second phase of the contract. The goal of this phase is to explore the response of the diffuser to time-dependent, downstream boundary conditions. The primary purpose is to provide benchmark data for testing related theoretical efforts in progress at MDRL and elsewhere. The experimental results should also help define the role of the inlet diffuser response in coupled inlet/combustor oscillations in ramjets[6].

2. RESEARCH OBJECTIVES

The specific objectives of the second phase of the contract are as follows:

1) Design and build appropriate hardware suitable for creating nearly planar, periodic waves downstream of the diffuser model.

2) Obtain detailed steady and dynamic measurements of the surface pressures and shock positions at various pressure ratios and perturbation parameters.

3) Obtain phase-averaged flowfield velocity and velocity fluctuation measurements at selected test parameter combinations.

4) Reduce, analyze, and document data in a form useful for comparison with theoretical prediction methods.

3.1 Diffuser Model

The diffuser model used in this research (Figure 1) was available from a parallel, MDRL-sponsored experimental effort. The model, being a third-generation design, incorporates the experience from three years of similar work. The exit-to-throat area ratio is 1.52, the ratio of divergent length to throat height is 7.2, and the aspect ratio of the throat cross-section is 4. Throat height is 44 mm. Sidewall and bottom boundary-layer growth is limited by three sets of ram-type suction slots, with independently controlled and measured flow rates through each set. The sidewalls are 2.54-cm-thick, schlieren-quality glass panels.

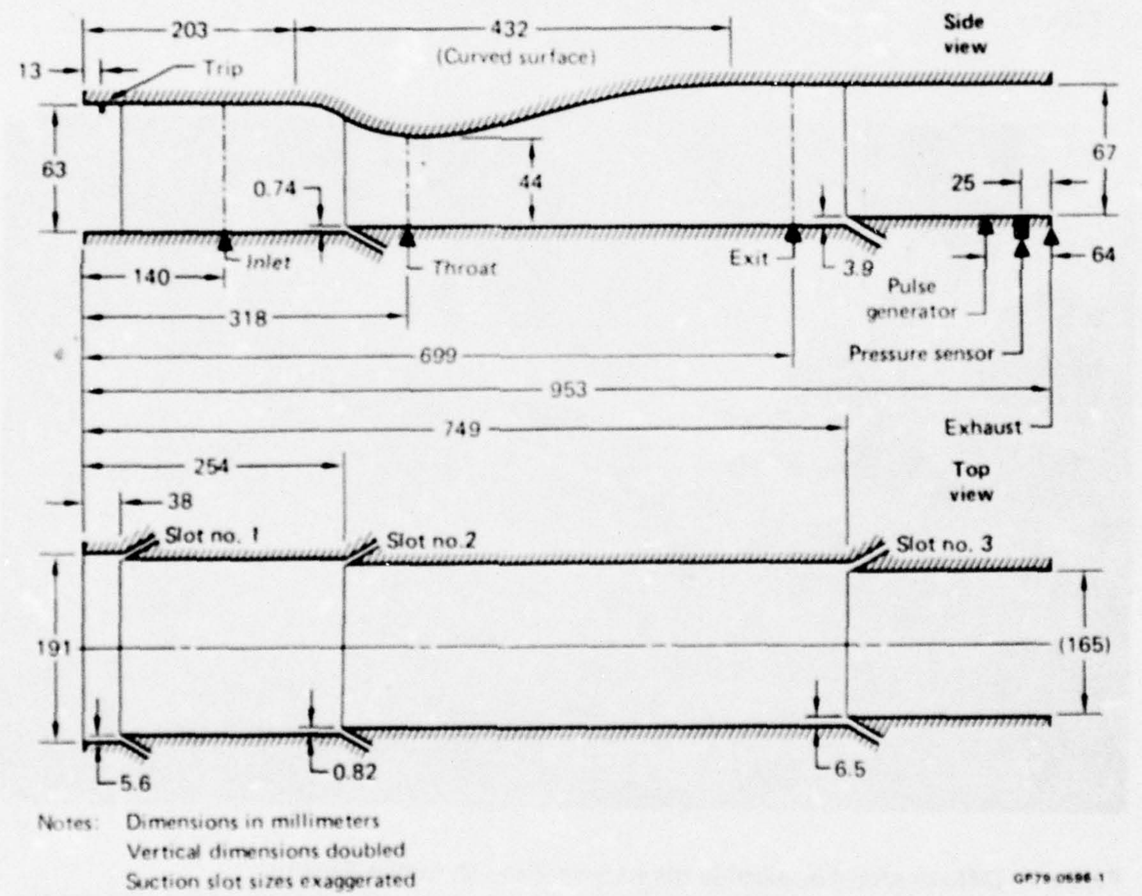

Figure 1. Dimensions of the diffuser model.

The model is supplied with clean, dry air through a plenum chamber equipped with a 25:1 area ratio contraction section. The air exhausts to the laboratory, keeping the exit pressure constant. Shock strength is varied by controlling the plenum chamber pressure and thereby the overall pressure ratio, ν (ratio of plenum total to exit static pressures). Shock strength increases monotonically with ν; the strongest obtainable shock Mach number is $M_{SH} = 1.35$.

The model is extensively instrumented with numerous surface-pressure measuring orifices and high-response surface-pressure transducers. An optical system with two 51-cm diam concave mirrors is used to obtain shadowgraph and schlieren photographs, and motion pictures. Used in connection with a line-scan imaging camera and appropriate electronics, the system also provides a time-dependent analog signal proportional to streamwise shock position.

A photograph of the model, installed and fully instrumented, is shown in Figure 2.

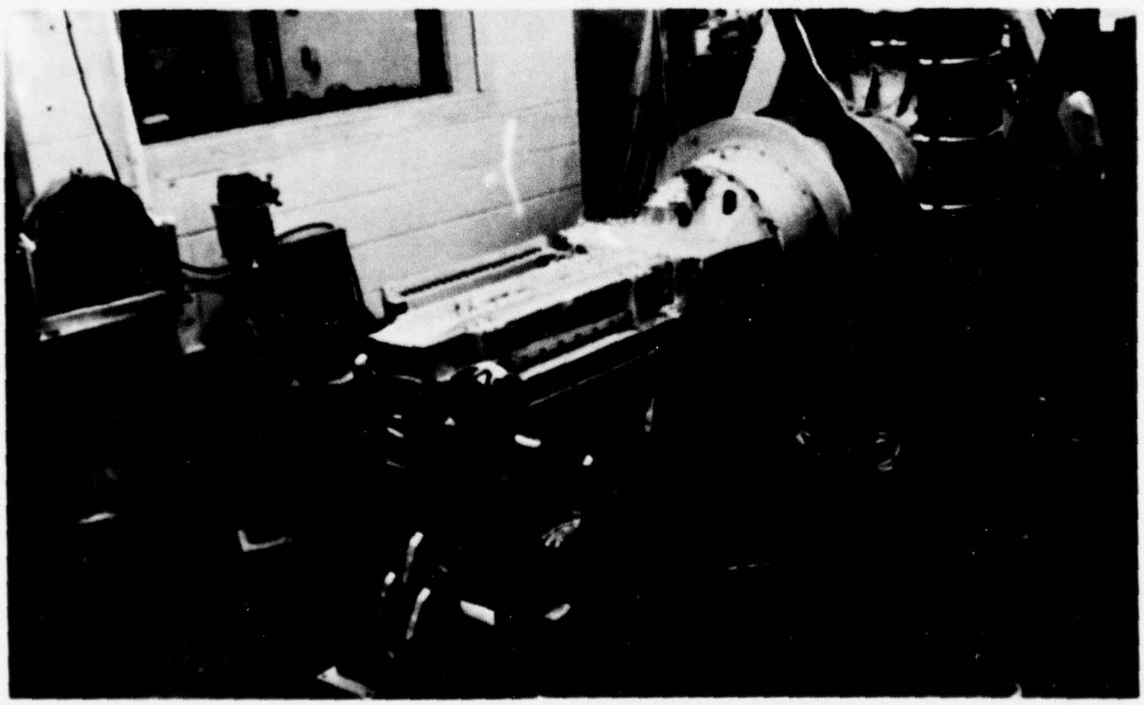

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Figure 2. Diffuser model installed in the Internal Fluid Dynamics Facility. Pulse generator motor and encoder visible on near and far sides of model, respectively. Ducts below model connect BLC suction slot manifolds to vacuum pump. Components of schlieren system are visible.

3.2 Perturbation Generator

A detailed study of possible methods to generate perturbations led to selection of the mechanical device shown in Figure 3. The active element is a rotor of rectangular cross section, embedded in the bottom wall of the model and rotated around its axis by a variable-speed motor. The rotor modulates the exit area from 0 to -9.5%, which was found to produce a 4-cm shock discplacement amplitude. Frequencies are continuously variable to 150 Hz, and rotor immersion can be varied stepwise from 0 to 6.3 mm. The rotor can be

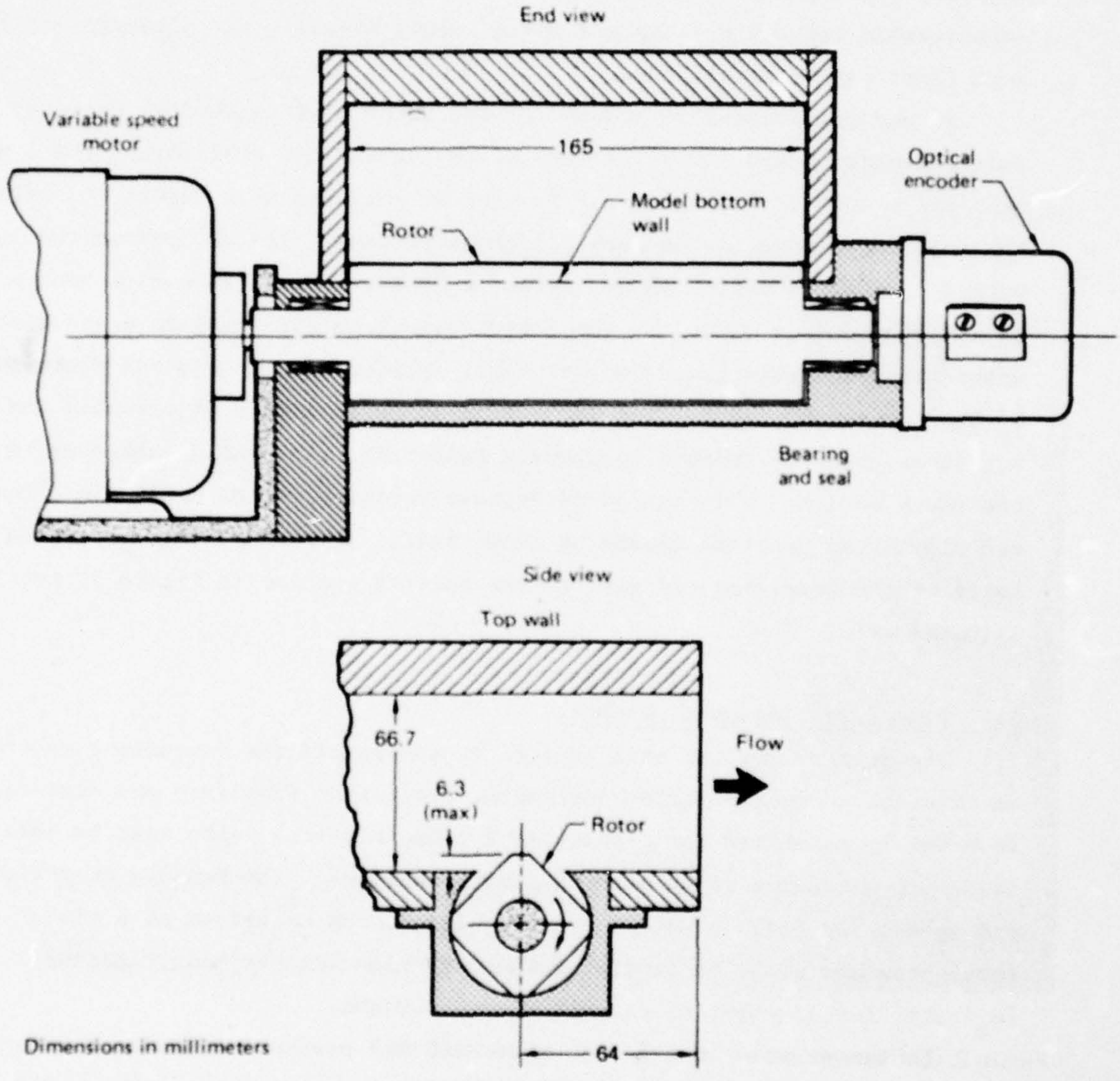

Figure 3. Disturbance generator used to periodically modulate diffuser exit area.

locked to present a flat boundary surface to the wall, corresponding to the baseline case of perturbation-free flow.

The area modulation produces pressure waves that propagate in the upstream direction. As the wave fronts recede from their point of origin, their radius of curvature increases and they become increasingly more planar. The wall pressures are monitored on both top and bottom walls at the exit station, located approximately three duct heights upstream of the generator. The pressure wave forms are recorded, phase averaged, and used as exit boundary conditions for related theoretical efforts. By examining the phase relationship between the top and bottom probe signals, the planarity of the wave front can be established.

An optical encoder is mounted on the rotor shaft with dual outputs: 1 pulse/revolution and 360 pulse/revolution signals are available. The 1 pulse/revolution output of the encoder is used as a synchronous signal to initiate the sampling period in the data reduction process. The 360 pulses/revolution output is used to define phase angles in data sampling, in conjunction with an adjustable counter circuit. The latter signal is also used to drive a stepping-motor mounted eight-bladed chopper wheel placed on the axis and near the slit of the schlieren system. The light beam is periodically interrupted and the schlieren image is strobed to provide real-time, slow-motion observation of the shock motion. This system references strobing to the excitation frequency and eliminates problems caused by minor drifts in either frequency. The drive motor of the generator and part of the rotor are shown in Figure 2, near the diffuser exit.

3.3 Flowfield Diagnostic Method

The primary goal of this project is to explore the dependence of the flow on external parameters (shock strength, excitation frequency and amplitude). In order to establish the respective trends, numerous tests must be made involving extensive variations of flow parameters. The demands of reliability and speed, implicit in such a program, led to the selection of a miniature total-pressure probe to determine the core flow velocity distributions $[u_c(x,t)]$ for a number of parameter combinations.

The sensor used is a Kulite model XCQ-062 pressure transducer, mounted on a sting at a fixed vertical distance (19 mm) from the bottom wall. The actuator is built into a removable panel fitted to the bottom wall. The sensor diameter is 1.6 mm and causes no measurable disturbances in the wall pressure distributions, with the exception of an approximately 2-cm long region on the bottom wall behind the sting.

The probe signal is recorded on FM tape simultaneously with reference pulses from the encoder of the perturbation generating system, thereby establishing a common time base. Phase averages are determined by processing the digitized data.

3.4 Boundary Layer Control (BLC) Tuning

In a series of preliminary test runs, the flow rates removed through each of the three slot sets were measured as functions of the respective suction manifold pressures (normalized by the total pressure at the diffuser inlet). In normal operation, the manifold pressures are monitored and the individual bleed flow rates are computed using the calibrated relations. The sum of the computed bleed rates is compared with the total bleed flow which is also independently monitored. The computed and measured flow rates routinely agree within about 5-6%, which is satisfactory. This arrangement requires only one flow meter for the BLC system instead of three.

The fraction of the flow removed at each slot is approximately equal to the ratio of the slot area to the cross-sectional area of the diffuser model at the slot. The respective area fractions for the three slot sets are: 0.059, 0.023 and 0.128. No fluid is removed between the throat and the exit station; thus, mass flow is conserved in the experiment, as also assumed in the related theories.

3.5 Baseline Data - No Excitation

All data in the second contract year were taken without excitation to establish a baseline for the assessment of response characteristics.

A family of normalized surface pressure distributions is shown in Figure 4. These data are repeatable with high precision (± 0.002). The "bump" near the throat is caused by a machining imperfection in the top wall contour. The irregularity is noticeable but inconsequential, and no attempt was made to eliminate it. The increasingly sharp "kink" at the beginning of the post-shock subsonic region indicates the appearance of shock-induced separation. The experiment thus is capable of producing both attached and separated transonic flows.

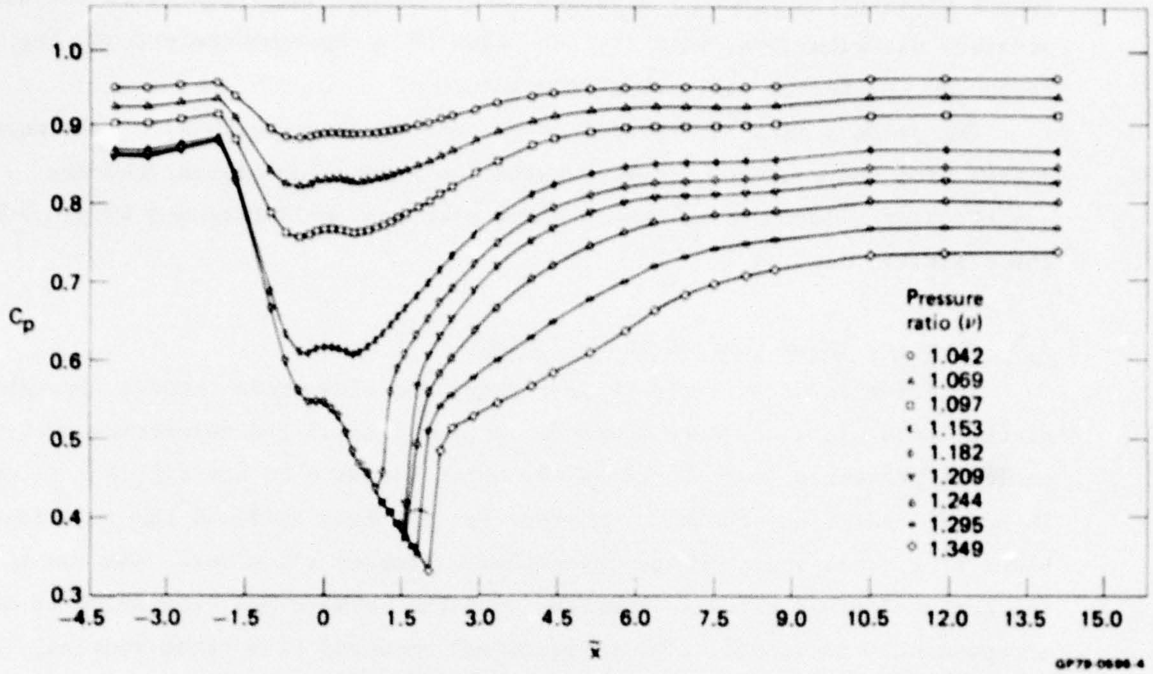

Figure 4. Top-wall surface-pressure distributions for various pressure ratios.

Inlet velocity profiles were measured using a miniature total pressure probe (0.08 mm x 0.32 mm frontal cross section). The profiles (Figure 5) are well behaved and thin: the blockage at the inlet station ($\tilde{x}$ = -5.1) is approximately 2.2%.

The exit station velocity profiles were measured with a total pressure probe rake having 11 total pressure tubes (0.81 mm o.d.) aligned vertically. The rake was traversed horizontally to cover the entire cross section (Figure 6). The influence of the sidewall boundary layers on the central portion of the flow is clearly minimal. The residual deviation from two-dimensionality on the right side of Figure 6 was traced to an asymmetry in the second suction slot and has been corrected.

Preliminary shock position and oscillation amplitude data were obtained by visual observation of the schlieren image of the flow (Figure 7). For weak shocks, the flow is remarkably stable, and the shock displays minor positional deviations only. As the shock strength is increased, increasingly larger amplitude oscillations develop, but even the largest amplitudes (at ν = 1.34) are only approximately ± 10% of the throat height. This amplitude is much smaller than that introduced by the perturbation generator, which should facilitate separating of the two types of motion in the data analysis.

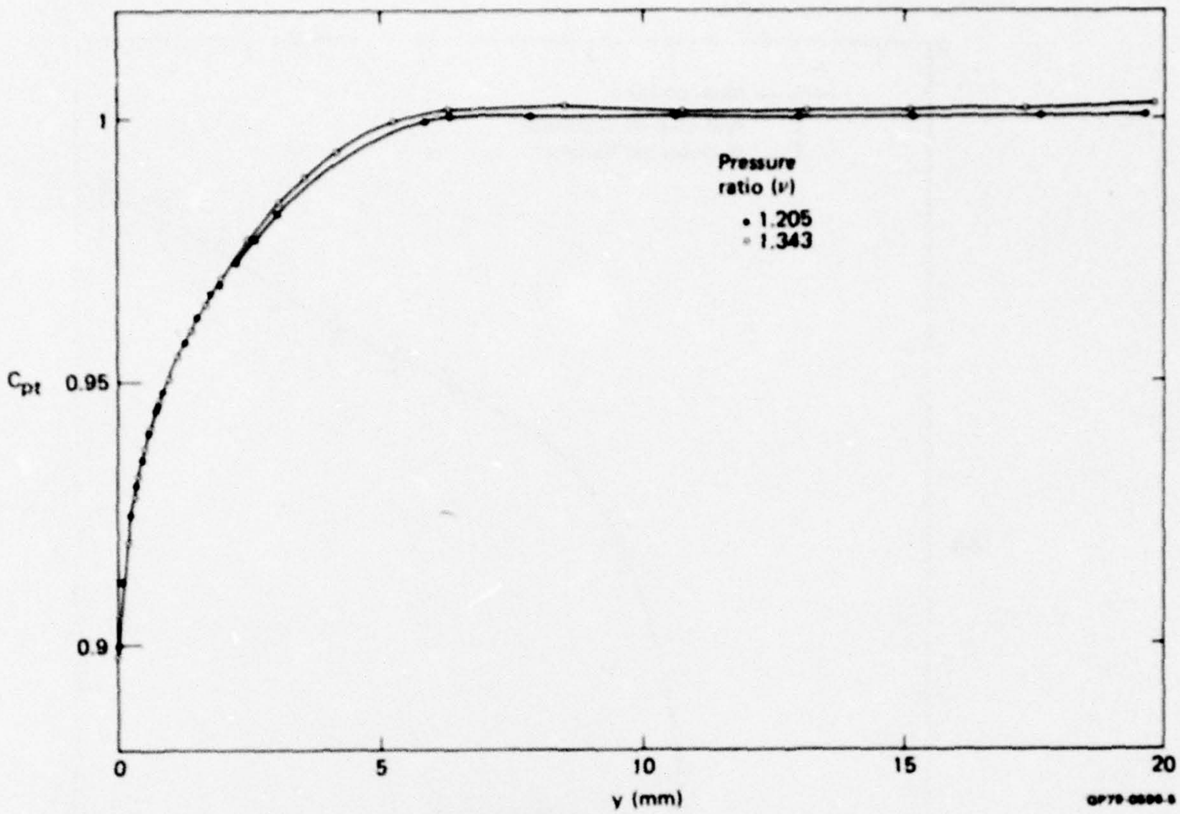

Figure 5. Total-pressure profile of boundary layer at top inlet center.

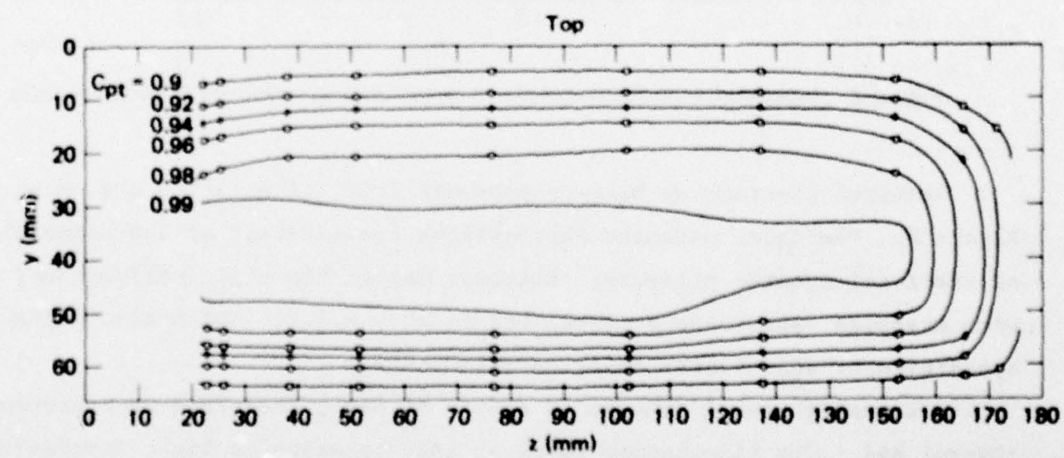

Figure 6. Total-pressure contour map for exit station at ν = 1.205.

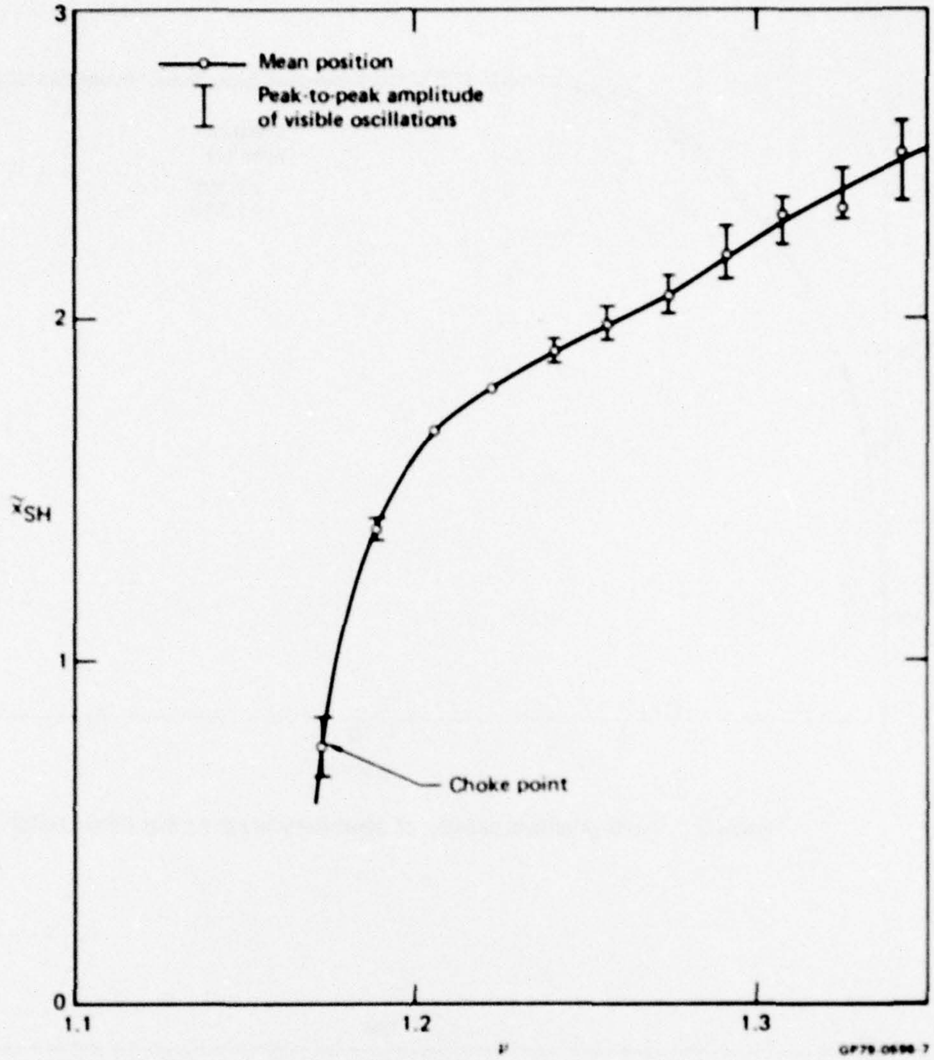

Figure 7. Mean shock position and shock amplitudes as functions of pressure ratio.

Selected fluctuating surface pressure (rms) intensities are shown in Figure 8. The inlet pressure fluctuations are constant at approximately 1% of the local dynamic pressure. Fluctuations at the exit stations increase with pressure ratio; steep growth begins at $\nu = 1.22$ (which also marks the appearance of appreciable shock oscillations).

A sensor (labeled exhaust in Figure 8) was placed 25.4 mm upstream of the channel end. The fluctuation level at this location is high, indicating that the conventional assumption of equating exhaust-station static pressure to ambient pressure may be significantly violated in this experiment.

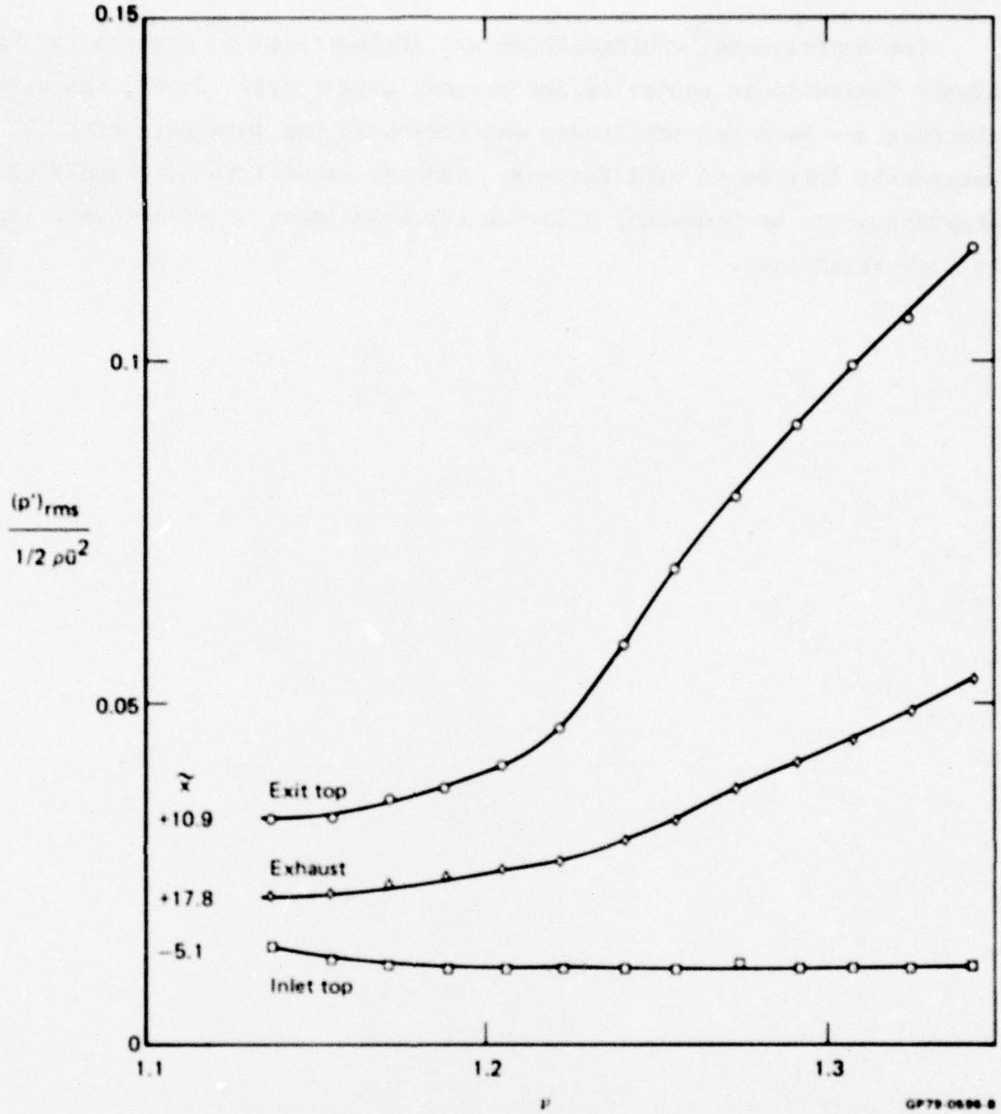

Figure 8. **Wall-pressure fluctuation intensity (rms) at various streamwise locations. (ū = local mean velocity).**

3.6 Summary

All necessary equipment and instrumentation required to achieve the contract objectives has been built, assembled, checked out, and placed in operation.

A large portion of the necessary baseline information has been acquired. Data acquisition is in progress.

The experimental configuration was demonstrated to possess two features highly favorable to achieving the program objectives. First, the natural fluctuations have low amplitudes and thus will not interfere with the study of externally introduced oscillations. Second, flows both with and without separation can be produced, allowing the assessment of effects attributable to flow separation.

4. PUBLICATIONS

A manuscript describing the results of the first phase of the contract is in preparation. This paper is intended for the AIAA Journal and is titled:

- The Effects of Approach Boundary Layer Properties on Shock Oscillations in a Diffuser Flow, by M. Sajben and J. C. Kroutil.

Related research work, sponsored by MDRL, led to two papers, both accepted by the AIAA Journal:

- Real-Time Optical Measurements of Time-Dependent Shock Position, by M. Sajben and R. C. Crites
- Shock-Wave Oscillations in a Transonic Diffuser Flow, by C. P. Chen, M. Sajben, and J. C. Kroutil.

5. PROFESSIONAL PERSONNEL

- Miklos Sajben, Senior Scientist
- Joseph C. Kroutil, Lead Engineer - Design

6. INTERACTIONS

Several seminars were given by M. Sajben, which included material resulting from the present contract.

1) USAF, Flight Dynamics Laboratory
   Wright-Patterson Air Force Base, Dayton, OH
   Host: Dr. G. K. Richey
   19 March 1979
2) University of Michigan
   Ann Arbor, MI
   Host: Prof. T. C. Adamson
   20 March 1979
3) NASA-Lewis Research Center
   Cleveland, OH
   Host: Dr. B. H. Anderson
   22 March 1979
4) Case Western Reserve University
   Cleveland, OH
   Host: Professor I. Greber
   23 March 1979

Experimental results from the initial stages of this work have been used to validate numerical computations carried out at NASA-Ames Research Center.[7] The work at Ames was done by Dr. T. J. Coakley, who used several types of turbulence models in time-averaged Navier-Stokes calculations to predict flows for the MDRL diffuser model.[5] The predicted time-mean flows agree well with the experimental data.

The experience and understanding gained from this work enabled M. Sajben to provide useful inputs to McDonnell Douglas Astronautics Company (MDAC) in connection with the design of a ram-jet missile propulsion system. The ram-jets considered by MDAC employ dump-combustors which are prone to develop screech or buzz.[6] It is believed that the coupling between the combustor and the diffuser is an important factor in determining this type of instability.

7. NEW DISCOVERIES

No invention disclosures were filed during the second year of this contract. The results obtained are of a scientific import with a primary purpose to assist development of predictive theories.

8. RELATED RESEARCH

The contract work is complemented by a parallel IRAD effort, which was initiated in 1976. During the second year of the present contract, this IRAD effort included both experimental and theoretical contributions.

The experimental work dealt with the effects of area ratio on the dynamics of diffuser flow and established the generally destabilizing effects of increasing area ratio. The improvement of velocity-field measurement capabilities at MDRL also was an objective.[8]

The theoretical effort (by Dr. Meng-Sing Liou) produced an operational computer code suitable for predicting time-dependent, viscous, transonic flow in a two-dimensional diffuser, subject to time-dependent boundary conditions. The theory is capable of predicting buzz-like instabilities.[8]

9. REFERENCES

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3. C. P. Chen, M. Sajben, and J. C. Kroutil, Shock-Wave Oscillations in a Transonic Diffuser Flow, AIAA Paper No. 78-204 (1978).
4. Unsteady Transonic Flow in a Two-Dimensional Diffuser, McDonnell Douglas Report MDC Q0636, 1 December 1977.
5. M. Sajben and J. C. Kroutil, Unsteady Transonic Flows in a Two-Dimensional Diffuser, AFOSR-TR-78-1277, May 1978 (Annual Technical Interim Report on AFOSR Contract No. F49620-77-C-0082).
6. T. Rogers, Combustion Instability in Dump Combustor Ramjets, 15th JANNAF Combustion Meeting, August 1978, To appear in JANNAF CPIA No. 297.
7. T. J. Coakley and M. Y. Bergmann, Effects of Turbulence Model Selection on the Prediction of Complex Aerodynamic Flows, AIAA Paper No. 79-0070 (1979).
8. McDonnell Douglas Research Laboratories Independent Research and Develcpment, Report MDC Q0853-4, Vol. 1, January 1979, Project No. 94006.

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